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ADP023750

TITLE: Global Ocean Prediction Using HYCOM

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TITLE: Proceedings of the HPCMP Users Group Conference 2007. High Performance Computing Modernization Program: A Bridge to Future Defense held 18-21 June 2007 in Pittsburgh, Pennsylvania

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Global Ocean Prediction Using HYCOM

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Abstract

In the third year of this project, fully-global eddy-resolving simulations have been performed using the HYbrid Coordinate Ocean Model (HYCOM) at 1/12° (~7 km mid-latitude) resolution. HYCOM is isopycnal in the open, stratified ocean, but makes a dynamically smooth transition to a terrain-following coordinate in shallow water and to pressure coordinates in the mixed layer and/or unstratified regions via the layered continuity equation. This approach incorporates the advantages of these three distinct vertical coordinate types into one ocean model that includes the deep ocean as well as coastal regions. In addition, it is designed for high vertical resolution in the surface mixed layer.

The majority of the first and second year simulations were atmospherically forced only (no data assimilation). In the second year and third year we added cases with ocean data assimilation. Since December 2006 we have run a nowcast every day, and since February 2007 we perform a nowcast and a 3-day forecast every day in real time. Results from HYCOM's data-assimilative hindcast of 2004 are compared to observations and to the existing operational nowcast/forecast system at the Naval Oceanographic Office.

1. Introduction

One important aspect of ocean model design is the choice of the vertical coordinate system. Traditional ocean models use a single coordinate type to represent the vertical, but model comparison exercises performed in Europe DYnamics of North Atlantic MOdels (DYNAMO) (Willebrand, et al., 2001) and in the United States Data Assimilation and Model Evaluation Experiment (DAMÉE) (Chassignet, et al., 2000) have shown that none of the three main vertical coordinates presently in use (depth [z-levels], density [isopycnal layers], or terrain-following [σ-levels]) can by itself be optimal everywhere in the ocean. The HYCOM (Bleck, 2002), is configured to combine all three of these vertical coordinate types. It is isopycnal in the open, stratified ocean, but uses the layered continuity equation to make a dynamically smooth transition to a terrain-following coordinate in shallow coastal regions, and to z-level coordinates in the mixed layer and/or unstratified seas. The hybrid coordinate extends the geographic range of applicability of traditional isopycnic coordinate circulation models toward shallow coastal seas and unstratified parts of the world ocean. It maintains the significant advantages of an isopycnal model in stratified regions while allowing more vertical resolution near the surface and in shallow coastal areas, hence providing a better representation of the upper ocean physics. HYCOM is designed to provide a major advance over the existing operational global ocean prediction systems, since it overcomes design limitations of the present systems as well as limitations in vertical and horizontal resolution. The result should be a more streamlined system with improved performance and an extended range of applicability (e.g., the present systems are seriously limited in shallow water and in handling the transition from deep to shallow water).

Global HYCOM with 1/12° horizontal resolution at the equator (~7 km at mid-latitudes) is the ocean model component of an eddy-resolving operational nowcast/forecast system scheduled for transition to the Naval Oceanographic Office (NAVOCEANO) at the end of calendar year 2007. It will provide nowcasts and forecasts of the three-dimensional (3D) global ocean

0-7695-3088-5/07 $25.00

environment. HYCOM will be coupled to the Los Alamos CICE sea-ice model (Hunke and Lipscomb, 2004) via the Earth System Modeling Framework (ESMF) (Hill, et al., 2004). Coupling between the ocean and ice models will more properly account for the momentum, heat and salt fluxes at the ocean/ice interface. The final component of the nowcast/forecast system is the Naval Research Laboratory Coupled Ocean Data Assimilation (NCODA) which is a multivariate optimal interpolation scheme that assimilates surface observations from satellites, including altimeter and Multi-Channel Sea Surface Temperature (MCSST) data, sea ice concentration and also profile data such as expendable bathythermographs (XBTs), conductivity temperature depth (CTDs) and ARGO floats (Cummings, 2005). By combining these observations via data assimilation and using the dynamical interpolation skill of the model, the three-dimensional ocean state can be accurately nowcast and forecast.

2. Model Setup

The global model is configured on a Mercator grid from 78°S to 47°N, while north of this latitude an Arctic dipole patch is used to avoid the singularity at the pole. The current 1/12° equatorial resolution translates to an array size of 4,500 × 3,298, with 32 hybrid layers in the vertical. HYCOM was initialized using temperature and salinity from the 1/4° Generalized Digital Environmental Model (GDEM3) climatology. In the first two years of the project, the majority of the global experiments were non-assimilative and used climatological monthly mean wind and thermal forcing constructed from the 1.125° European Center for Medium-Range Weather Forecasts (ECMWF) Re-Analysis (ERA15) over the 1979–1993 time frame with 6-hourly variability from the ECMWF operational model over the period September 1994–September 1995 added to get realistic simulation of the surface mixed layer. In order to keep the evaporation-precipitation budget on track, the model weakly relaxes to the Polar Science Center Hydrographic Climatology sea surface salinity (Steele, et al., 2001). In the current, third, year of the project we continue to run non-assimilative cases, now with the newer ERA-40 Re-Analysis corrected by satellite climatologies, but our primary focus is on cases than assimilate oceanic data. These start from, and are data-assimilative twins of, an extension of a climatologically forced experiment with interannual wind and thermal forcing from the 2003–2007 3-hourly Fleet Numerical Meteorology and Oceanography Center (FNMOC) Navy Operational Global Atmospheric Prediction System (NOGAPS). Since December 2006 we have run a nowcast every day, and since February 2007 we perform a nowcast and a 3-day forecast every day in real time. Results are at http://www7320.nrlssc.navy.mil/GLBhycom1-12/skill.html.

3. Assimilative Global HYCOM Evaluations

An important aspect of preparing a new system for potential operational use is to compare it to the comparable existing operational system. In this case the current operational system is 1/32° near-global Navy Layered Ocean Model (NLOM) (Wallcraft, et al., 2003) with 6 layers in the vertical in combination with the 40-level 1/8° global Navy Coastal Ocean Model (NCOM) (Barron, et al., 2006; and Kara, et al., 2006). NLOM is used to assimilate Sea Surface Height (SSH) along altimeter tracks with the model forecast as a first guess for each analysis cycle and to make 30-day ocean weather forecasts. NCOM assimilates steric SSH anomalies from NLOM in the form of synthetic temperature (T) and salinity (S) profiles (Rhodes, et al, 2002) and makes 4-day forecasts. This two-model global system requires less computer power than a single global model with both high horizontal and high vertical resolution. Note that these system measure horizontal resolution at mid-latitudes, so 1/8° NCOM is actually 2.2x coarser than 1/12° HYCOM (~15 km vs. ~7 km at mid-latitudes). The intent is for HYCOM to replace both components of the existing system, and in particular HYCOM will replace NCOM as the provider of boundary conditions for regional and coastal models.

Figure 1 compares surface eddy kinetic energy (EKE) in the Gulf Stream region from a) observations based on 1990–1999 surface drifters (Fratantoni, 2001) to b) the operational NCOM system and c) the hindcast HYCOM system, both in 2004. The white lines show the long term mean and standard deviation of the Gulf Stream pathway. It is evident that HYCOM is capturing a significantly larger fraction of the variability than NCOM. The data-assimilative HYCOM also out-performs non-assimilative HYCOM (not shown). Figure 2 compares the subsurface temperature at 140W,2N down to 300m in 2004 from the TAO buoy at 140W,2N with operational NCOM and the hindcast HYCOM system. Figure 3 shows the corresponding temperature difference between the models and the TAO observations. The TOA profiles are assimilated into HYCOM when they are available in real time, as indicated on the figures. HYCOM has a tighter and more realistic thermocline than NCOM, with smaller temperature errors. However, HYCOM's skill is reduced significantly during the periods when the TAO profiles are not assimilated.

4. Plans

We are on track to transition the system to NAVOCEANO by the end of the calendar year. Our evaluation will continue in fiscal year 2008, with particular focus on sea-ice assimilation. We will start preparing for follow on systems by performing four one year advanced data assimilation hindcasts (and associated

forecasts) to explore more expensive alternatives to the initial data assimilation method. If these work as well as expected, they will form the basis for an upgrade to the initial HYCOM system at NAVO in FY 09. Altimeter data are available starting in 1993, so we will complete a 1993–present "ocean re-analysis" by running a hindcast from 1993. In addition we will complete a 1995–2007 NOGAPS-forced non-assimilative simulation and a similar simulation from 1979–2006 with ECMWF forcing. These interannual simulations, and the data-assimilative 1993–present hindcast, are an unprecedented opportunity to study regional oceanography and dynamics at high resolution in the context of the global ocean.

Acknowledgments

This work was supported in part by a grant of computer time from the Department of Defense High Performance Computing Modernization Program at the Naval Oceanographic Office and Engineer Research and Development Center Major Shared Resource Centers. It was sponsored by the National Ocean Partnership Program (NOPP) and the Office of Naval Research (ONR) through the following projects: NOPP US Global Ocean Data Assimilation Experiment: Global Ocean Prediction with the HYbrid Coordinate Ocean Model (HYCOM), 6.1 NRL (ONR): Global Remote Littoral Forcing via Deep Water Pathways, and 6.1 University of Miami (ONR): Further Developments of HYCOM.

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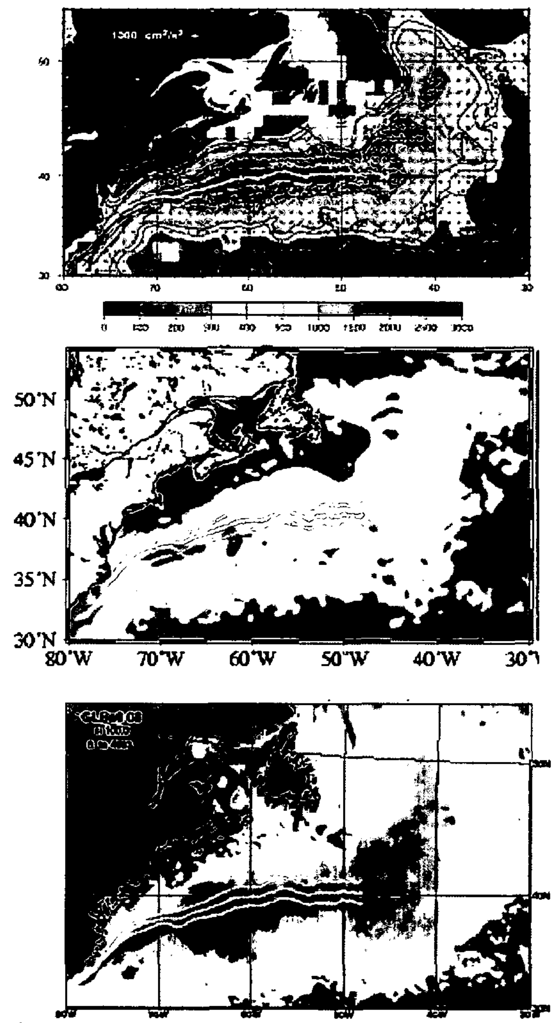

Figure 1. Surface eddy kinetic energy (EKE) in the Gulf Stream region from a) observations based on 1990–1999 surface drifters (Fratantoni, 2001), b) the operational NCOM system in 2004, and c) the hindcast HYCOM system in 2004. The white lines show the long term mean and standard deviation of the path of the Gulf Stream.

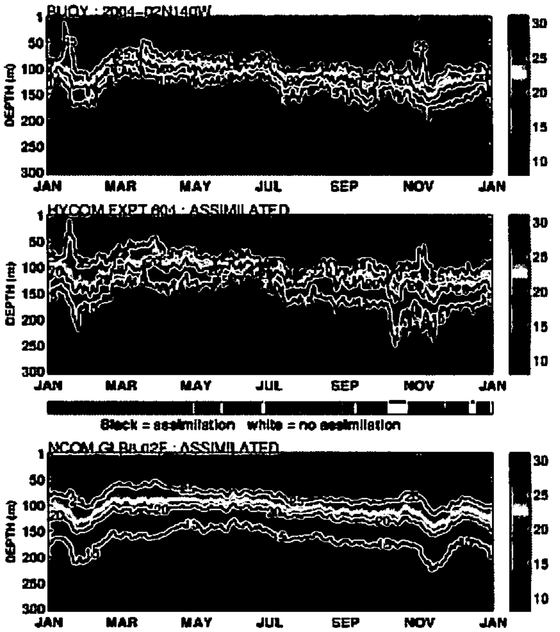

Figure 2. Subsurface temperature at 140W,2N down to 300m in 2004 from a) the TAO buoy, b) hindcast HYCOM and c) operational NCOM. The black and white bar indicates when TAO profiles where assimilated into HYCOM.

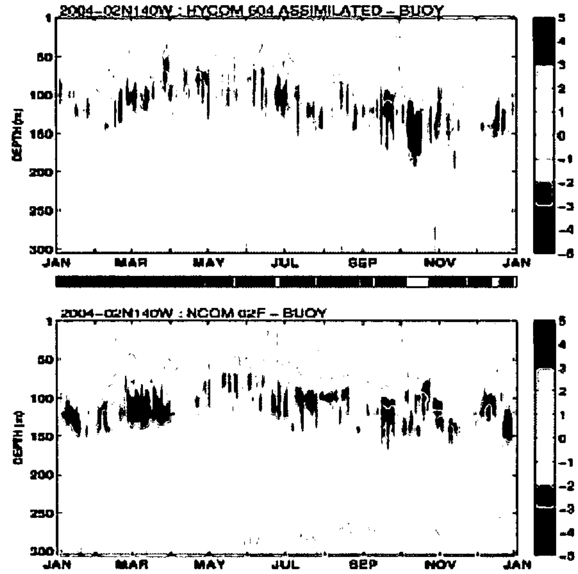

Figure 3. The corresponding temperature difference at 140W,2N down to 300m in 2004 between the TAO buoy observations and a) HYCOM and b) NCOM.